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Spread of the Introduced Climbing Perch (*Anabas testudineus*) in the Fly River System, Papua New Guinea, with Comments on Possible Ecological Effects

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ABSTRACT

The introduction and spread of Climbing Perch *Anabas testudineus* Bloch, through the Fly River system, Papua New Guinea is documented. From it's first recording on the middle Fly floodplain in 1988, the species spread rapidly throughout the system over succeeding years.

Dietary intake of *A. testudineus* was determined from gut content analysis. The majority of contents consisted of detritus, but with a considerable intake of aquatic and terrestrial invertebrates and macrophytes. Dietary composition and size-frequency distribution of populations of *A. testudineus* in freshwater and estuarine habitats were compared and reasons for differences postulated. Dietary overlap between *A. testudineus* and the majority of 62 native fish species was insignificant. Many of those species for which significant overlaps were recorded occurred mainly in different habitats or had different feeding habits, likely targeting different prey items within the broad food groups. A suite of species was identified with which *A. testudineus* may compete, however, the extent of any effect was difficult to predict from the limited dietary data and fish sampling information available.

Other potential ecological impacts on the native fish fauna are discussed in relation to (a) the physical disturbance of habitats as a result of the feeding habit of *A. testudineus*, and (b) choking of piscivorous species preying upon *A. testudineus*. A possible threat to the northern tropical regions of Australia through accidental transportation of *A. testudineus* across the Torres Strait has been identified.

Key Words: Introduced fish, Dietary overlap, Distribution, Competition.

INTRODUCTION

The Climbing Perch, *Anabas testudineus* Bloch 1795 (Anabantidae: Perciformes), was first recorded in Papua New Guinea (PNG) in 1976 from the Morehead River close to the border with Irian Jaya (Kila and Polon 1994). Previous to this, the species was unrecorded from the island of New Guinea (comprising both Irian Jaya and mainland PNG), and is believed to have been transported from Java as part of the settlement of Irian Jaya by Indonesia.

A. testudineus is an unusual species in that it has a dual gas exchange mechanism with accessory respiratory organs which allow the fish to survive out of water for long periods. In addition, *A. testudineus* has hinged opercula and many stiff spines allowing it to "walk" across land from one waterbody to the next (Davenport and Abdul Matin 1990). *A. testudineus* is common throughout the Indian sub-continent and south-east Asia, and is widely cultured as a food item (Davenport and Abdul Matin 1990). As a result of its commercial importance, the species has been the topic of various studies (e.g. salinity tolerance, Khan et al. 1976; oxygen uptake, Mishra and Singh 1979; feeding habits and dietary composition, Singh and Samuel 1981, Nargis and Hossain 1987, Pandey et al. 1992; fecundity, Chanchal et al. 1978, Ramaseshaiah 1985; structure and function of its air breathing organ, Singh and Mishra 1980; and terrestrial locomotion, Davenport and Abdul Matin 1990).

After the first recording of *A. testudineus* from PNG in 1976, there were no subsequent documented reports of the species until April 1988 from Bosset Lagoon, on the Fly River floodplain, approximately 175 km to the north of the Morehead River. This paper documents the spread of *A. testudineus* in the Fly River system, describes the diet of the species, examines dietary overlap with other fish species in the river system and comments on the possible ecological effects of this accidental introduction.

DESCRIPTION OF STUDY AREA

The Fly River has an average discharge of 6000 $m^3 s^{-1}$, ranking 23rd, after the Niger and Danube (Welcomme 1985). It has a catchment area of 76 000 km^2, with the highest discharge per unit area of any major river system. The river is approximately 1100 km in length and flows southwards to the Gulf of Papua from its headwaters in the karstic Star Mountains of central New Guinea (Figure 1a). Rainfall in the upper catchment (to 3800 m above sea level) is in excess of 10 m per year and is evenly distributed across the year. On the floodplain, rainfall is approximately 3 m per year, the majority falling as a monsoon-influenced wet season from December to May. The high altitude, combined with high rainfall, seismic activity and unstable geology (limestone and shale rock types) results in naturally high sediment loads in the Fly River (10×10^6 Mg yr^{-1}) and its major tributary, the Strickland River (70×10^6 Mg yr^{-1}) (Smith and Bakowa 1994, Swales et al. 1998, 1999, 2000).

The majority of the river system is low lying; the river port of Kiunga lies 800 km from the sea by river but is only 20 m above sea level (Figure 1a). As a result there is a large, seasonally-inundated floodplain inland to Kiunga. Smith and Bakowa (1994) identified four major wetland habitats on the floodplain; blocked valley lakes (total area 245 km^2) where the Fly River acts as an hydraulic dam to back-flood tributaries to form broad, shallow lagoons; oxbow lakes (122 km^2) formed from cut-off meander bends of the river; and, grassed and forested floodplain (2473 km^2 combined). Oxbow lakes and the main river channel are permanently inundated, while blocked valley lakes dry-out in drought years (i.e. El Niño events such as 1982, 1986, 1993/94 and 1997) and much of the grassed and forested floodplain dries each year for variable periods.

The freshwater fish fauna of the Fly River system is diverse for the Australasian region. Roberts (1978) recorded 103 species from a range of freshwater habitats and Swales et al (1998) reported 128 species from 33 families. The feeding habits of the fish fauna are also diverse. From examination of gut contents, Roberts (1978) reported a range of feeding groups, including piscivores, aquatic and terrestrial insectivores, terrestrial vegetation (including fruit) eaters, molluscivores, *Macrobrachium* prawn eating species, algivores, detritivores and omnivores. Similar feeding groups were subsequently recorded by Maunsell and Partners (1982) and Kare (1991).

The Ok Tedi Copper Mine, a copper, gold and silver mine, is located on the Ok Tedi, a major tributary of the Fly River (Figure 1a). Extensive hydrological, chemical and biological monitoring programs have been conducted by the mining company since 1983 (Smith and Bakowa 1994.). Biological monitoring has concentrated on the fish fauna (*viz.* species diversity, biomass and bioaccumulation of metals) to satisfy the PNG government's criterion of maintaining a viable, subsistence fishery. Data presented in this study were incidentally collected as part of this monitoring program.

METHODS

Initially, routine monitoring of the system concentrated on freshwater sites in the upper catchment (1983 – 1985), however, over time the spatial and temporal extent of monitoring progressively increased to cover the whole freshwater system, and in 1990, monitoring was extended to the estuary of the Fly River, with associated control sites (Smith 1991). Most sites were sampled on a quarterly basis.

Sampling in freshwater reaches was principally by gill netting, using a standardised set of 13 gill-nets ranging in size from 25 to 175 mm stretched mesh, set over a 24 hr period at each site. At faster flowing riverine sites in the upper catchment (e.g. Ok Tedi at Ningerum) a reduced net set of eight nets up to and including the 125 mm net was used, and in addition, where exposed gravel and sand banks were present, six replicate hauls with a 50m beach seine with a 19 mm stretched mesh were taken. Floodplain sites were sampled with the full gill-net set. In addition, a standardised quantity of rotenone (powdered derris root; 500 g) was used to sample juvenile and smaller fish species. Sampling in the Fly River estuary and at control locations along the coast to the east (Bamu River estuary) and west (Daru coast) was with replicate beach seine hauls (4 hauls with a 187 m beach seine with a 50 mm mesh and 5 hauls with a 50 m seine with a 19 mm mesh). In addition, a brackish water swamp on Kiwai Island at the mouth of the Fly Estuary, used as a nursery area by Barramundi (*Lates calcarifer* Bloch 1790)(personal observations, REWS), was sampled using rotenone and seine netting. All fish from freshwater and estuarine sites were identified to species, measured (fork or total length) and weighed to the nearest gram. These data were utilised to compile listings of sites where *A. testudineus* was first recorded, to compare length-frequency distributions of populations from freshwater and estuarine habitats and to obtain specimens for dietary analysis.

Dietary analysis of a large range of fish species (17,067 specimens from 64 species) from freshwater reaches was conducted as part of early monitoring programs (1984-1987, Hortle 1986, Smith 1988) to assess broad dietary requirements. More recently, dietary studies of selected species have been initiated to compare dietary intake in riverine and floodplain habitats (Kare 1991), and to compare dietary intake in different floodplain habitats (forested and grassed oxbow lakes; 1993–1995; Roderick, unpublished data). Dietary intake by *A. testudineus* was determined to assess overlap between *A. testudineus* and historical data on other freshwater species inhabiting floodplain habitats and between *A. testudineus* from freshwater and estuarine habitats.

In the laboratory, the stomachs of *A. testudineus* were dissected from whole frozen fish. The stomach was opened without disturbing the contents, so that the percentage volume occupied by the contents in each stomach could be assessed visually. Percentages ranged from 0% (empty) to 100% (full), with 110% indicating a distended stomach. To allow comparisons with historical data on other species, gut contents were classified into ten broad dietary categories following examination under a stereo microscope. The percentage composition of food items in the gut contents was assessed visually and mean percentage volumes occupied by each food category were calculated.

The degree of dietary overlap between species was determined using the formula of Zaret and Rand (1971) which calculates a Coefficient of Overlap for each pair of species. A coefficient of ≥ 0.6 indicates a significant overlap in diet.

$$\hat{C}_{\lambda} = \frac{2\sum_{i=1}^{s} X_i Y_i}{\sum_{i=1}^{s} X_i^2 + \sum_{i=1}^{s} Y_i^2}$$

$\hat{C}_{\lambda}$ = Overlap coefficient
S = Total number of food categories
X_i = Proportion of total diet of species X from a given category of food i
Y_i = Proportion of total diet of species X from a given category of food i

RESULTS

A. testudineus was first recorded in the Fly River at Bosset Lagoon in April 1988. Subsequently it was taken from Lake Daviumbu in May 1988, and then in the Fly River near Obo in December 1988 (Figure 1a). The following years saw a rapid spread of the species throughout the system (Figure 1b – 1g). In April 1993 the species was also recorded from the inner and outer Fly River estuary (Figure 1f). Currently, the species is now present in all floodplain habitats, slow-flowing riverine reaches, coastal swamps and brackish parts of the estuary. The species has been opportunistically sampled from slow-flowing creeks in dense primary rainforest in the foothills near Kiunga (Storey and Smith, unpublished). Therefore, it is assumed that it occurs in similar habitats throughout the flooded forest of the floodplain. To date, *A. testudineus* has not been recorded from faster-flowing reaches of the upper Fly River or Ok Tedi.

The minimum sizes of *A. testudineus* in estuarine and freshwater habitats were comparable (46 mm versus 32 mm respectively); however, individuals from freshwaters were larger (mean = 166.2 mm, max = 269 mm, n = 2107) compared with those from estuarine habitats (mean = 79.6 mm, max = 154 mm, n = 170.) (Figure 2).

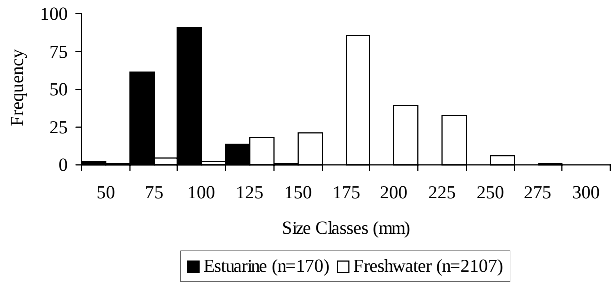
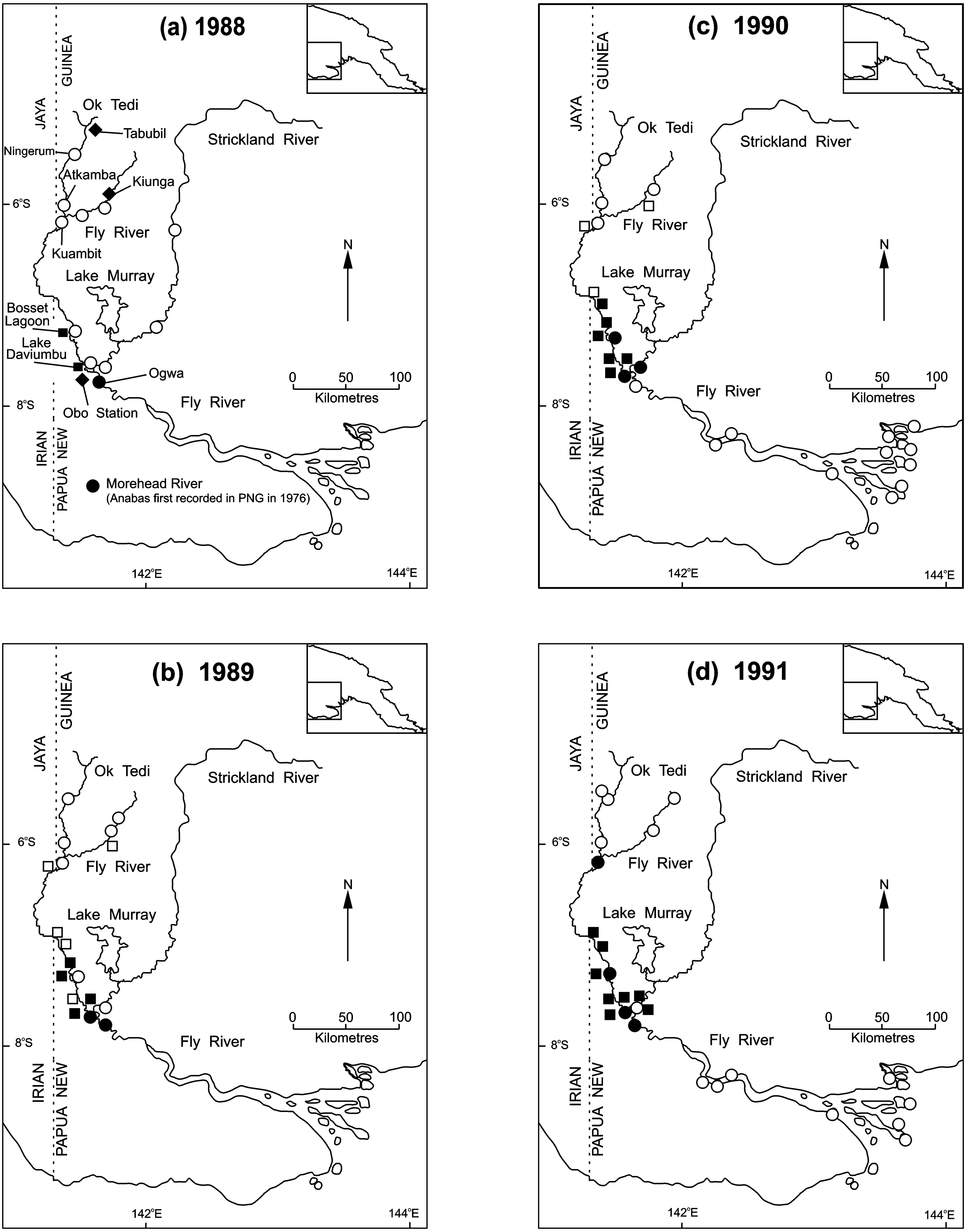
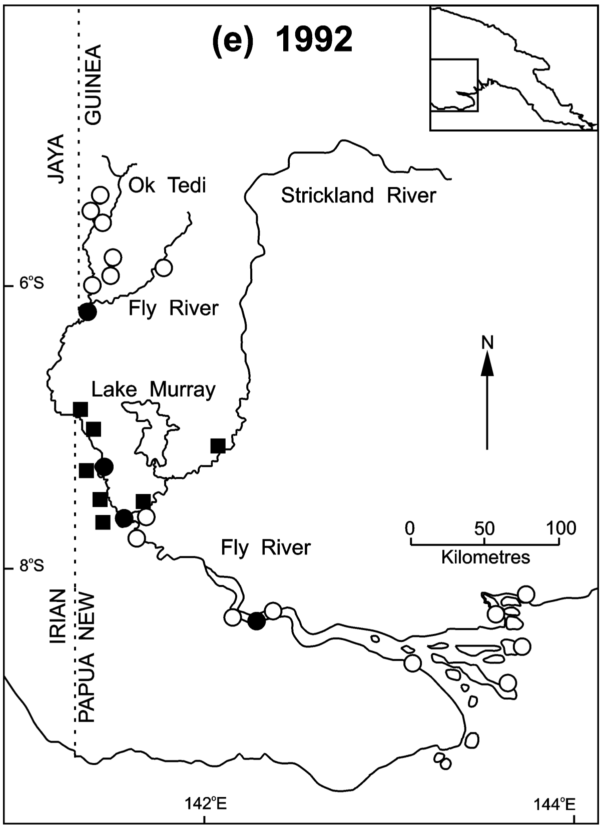
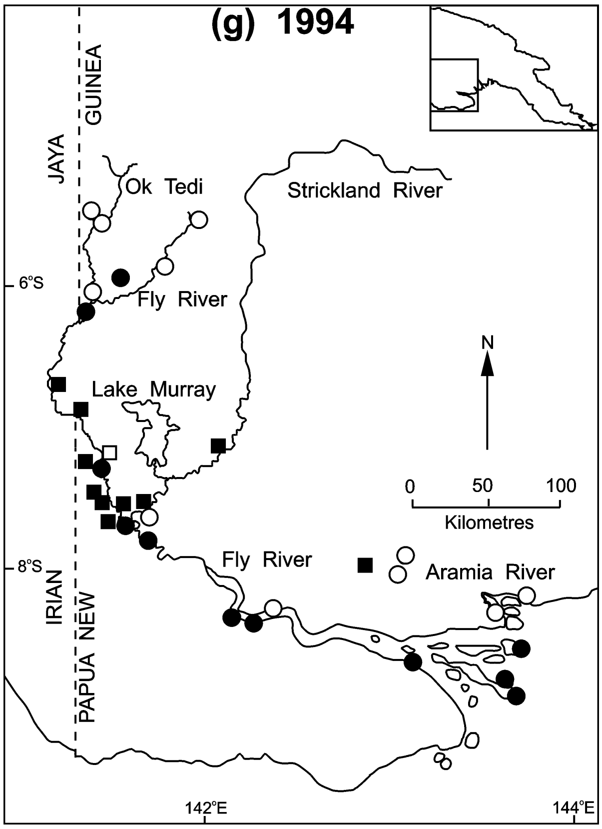


Figure 2. Size-frequency distributions of populations of *A. testudineus* from estuarine and freshwater habitats (frequency for freshwater locations = n x 10^{-1}).

Dietary composition of populations of *A. testudineus* from freshwater and estuarine habitats was similar (Table 1; Figure 3), with a significant dietary overlap (Coefficient of Overlap = 0.685).


(a) 1988
JAYA
GUINEA
IRIAN
PAPUA NEW
Ok Tedi
Tabubil
Ningerum
Atkamba
Kiunga
6°S
Kuambit
Fly River
Strickland River
Lake Murray
Bosset Lagoon
Lake Daviumbu
Ogwa
Obo Station
8°S
Fly River
N
0 50 100
Kilometres
Morehead River
(Anabas first recorded in PNG in 1976)
142°E
144°E
(b) 1989
Ok Tedi
Strickland River
6°S
Fly River
Lake Murray
8°S
Fly River
(c) 1990
Ok Tedi
Strickland River
6°S
Fly River
Lake Murray
8°S
Fly River
(d) 1991
Ok Tedi
Strickland River
6°S
Fly River
Lake Murray
8°S
Fly River





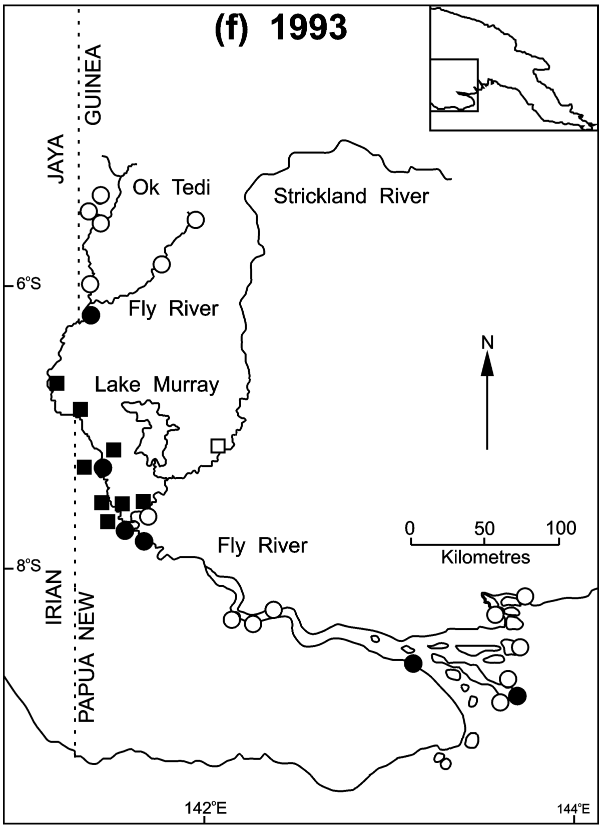


Figure 1 (a-g). Changes in the distribution of *Anabas testudineus* in the Fly River system from 1988 to 1994. Circles indicate riverine sites, squares indicate floodplain sites. Sites at which *A. testudineus* was taken are shaded.

Coefficients of dietary overlap between *A. testudineus* and 62 species of fish from the Fly River system (Table 2), indicated significant dietary overlap with 24 species. Sample sizes for specimens examined for each species range from 1 (*Ophieleotris aporos, Mogurnda mogurnda, Bostrichthys strigogenys*) to 1376 individuals (*Melanotaenia splendida rubrostriata*), although 10 or more individuals were examined for the majority of species. Results for species with small sample sizes should be treated with some caution, as their diets may not be accurately represented. However, the results are useful in that they provide some indication of broad food preferences.

Table 1. Mean percentages of each dietary category for freshwater and estuarine populations of *A. testudineus*.

Dietary category and Description	Mean percentage of dietary category Freshwater (n = 48)	Estuarine (n = 74)
1. Aquatic insects	25.8	1.0
2. Terrestrial insects	11.3	47.6
3. Aquatic plants	11.7	0.7
4. Terrestrial plants	5.0	8.4
5. Crustaceans	0	0
6. Fish	0.8	4.1
7. Other vertebrates	0	0
8. Molluscs	1.0	0
9. Oligochaetes 0.2	0.3	
10. Detritus/sediment	44.2	37.9

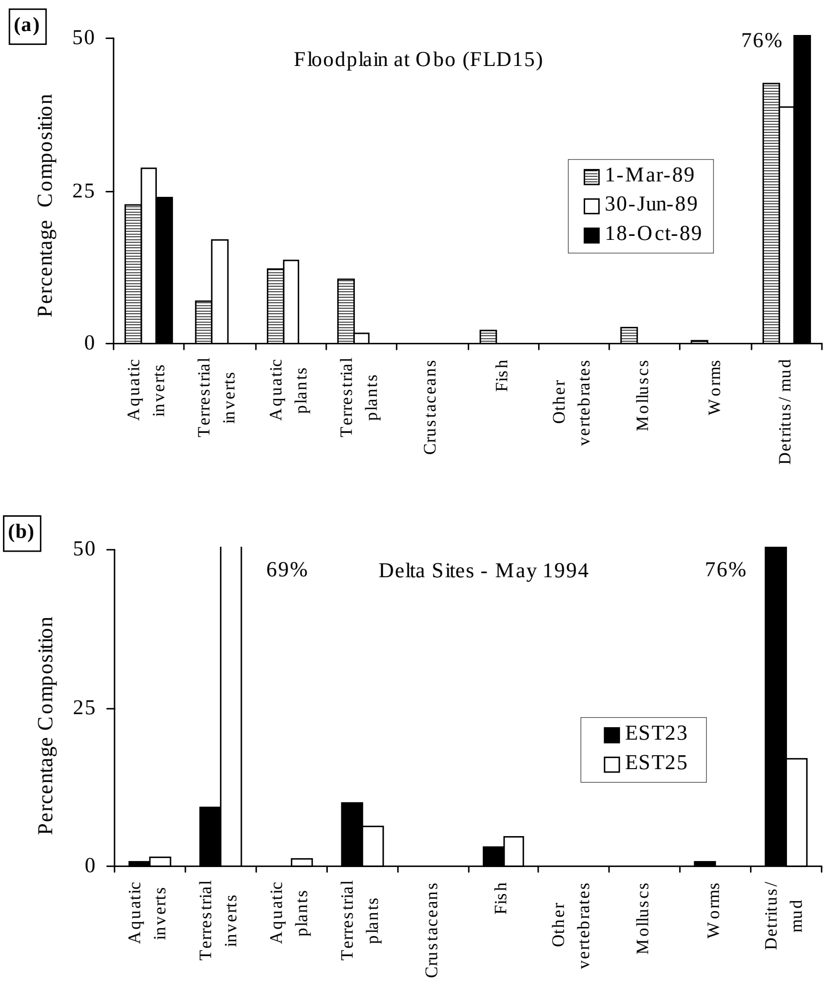


Figure 3. Mean percentage composition of each dietary category for (a) freshwater, and (b) estuarine populations of *A. testudineus*.

Table 2. Coefficient of Overlap between *A. testudineus* and 62 species of fish collected from freshwater reaches of the Fly River system. Species are ranked in ascending order of Coefficients and are assigned to four categories: 1, no significant overlap; 2, close to significant; 3, moderately significant; 4, highly significant.

Group	Species	n [a]	Coefficient	Main Food Types or Feeding Strategy/Habitat
1	*Ophieleotris aporos*	1	0.0032	Worms - bottom feeder
	Mogurnda mogurnda	1	0.0129	Bottom/mid water feeder
	Oloplotosus luteus	3	0.0164	Crustaceans - bottom feeder, upper catchment
	Lates calcarifer	329	0.0324	Piscivore
	Strongylura kreffti	233	0.0329	Piscivore
	Cinetodus froggatti	103	0.0564	Invertebrate feeder - gastropods
	Oxyeleotris lineolatus [b]	59	0.0670	Piscivore
	Nibea semifasciata	24	0.0751	Decapods and fish
	Datnioides quadrifasciatus	11	0.0945	Piscivore
	Cochlefelis danielsi	41	0.1066	Crustaceans - bottom feeder
	Oxyeleotris fimbriata	47	0.1228	Piscivore
	Megalops cyprinoides	105	0.1641	Piscivore
	Kurtus gulliveri	29	0.1732	Fish and macro-invertebrates
	Bostrichthys strigogenys	1	0.1743	Terrestrial invertebrates
	Cochlefelis spatula	161	0.1876	Bottom feeder
	Porochilus meraukensis	2	0.2001	Bottom feeder
	Glossogobius giurus	3	0.2035	Detritus/sediment
	Zenarchopterus novaeguinae	560	0.2132	Terrestrial invertebrates
	Acanthopagrus berda	4	0.2197	Aquatic invertebrates
	Glossamia aprion	135	0.2351	Fish and macro-invertebrates
	Thryssa rastrosa	78	0.2911	Aquatic invertebrates
	Toxotes lorentzi	31	0.2952	Invertebrates (terrestrial)
	Lutjanus goldei	8	0.3179	Fish
	Clupeoides papuensis	600	0.3354	Terrestrial invertebrates
	Toxotes chatareus	368	0.3609	Terrestrial invertebrates
	Denarusia bandata	5	0.3930	Invertebrates
	Arius taylori	125	0.4032	Terrestrial invertebrates and plant matter
	Pristis microdon	30	0.4265	Crustaceans and detritus
	Arius augustus	57	0.4338	Fish and Decapods
	Lutjanus argentimaculatus	7	0.4498	Fish and Decapods
	Pingalla lorentzi	2	0.4919	Aquatic plants and detritus
	Glossamia trifasciata	9	0.4989	Fish and invertebrates
	Thryssa scratchleyi	469	0.5204	Fish and aquatic invertebrates
	Neosilurus equinus	110	0.5367	Benthic feeder
2	*Cinetodus crassilabris*	32	0.5828	Aquatic invertebrates
	Arius macrorhynchus	465	0.5930	Terrestrial invertebrates and plant matter
	Scleropages jardinii [c]	349	0.5938	Fish and decapods - surface feeder
3	*Melanotaenia oktediensis*	16	0.6079	Terrestrial invertebrates and aquatic plants
	Melanotaenia splendida rubrostriata	1376	0.6292	Terrestrial invertebrates and detritus/sediment
	Variichthys lacustris	100	0.6305	Aquatic invertebrates and plants
4	*Hephaestus raymondi*	10	0.6786	Aquatic invertebrates
	Nematalosa spp	4	0.6844	Planktivores [d]
	Porochilus obbesi	99	0.7289	Aquatic plants and molluscs - benthic feeder
	Arius carinatus	85	0.7337	Invertebrates, aquatic and terrestrial
	Arius latirostris	1034	0.7337	Aquatic invertebrates
	Ambassis agrammus	307	0.7504	Invertebrates
	Glossogobius concavifrons	9	0.7541	Invertebrates and detritus/sediment
	Tetranesodon conorhynchus	4	0.7590	Generalist
	Parambassis gulliveri	604	0.7765	Invertebrates - aquatic and terrestrial
	Nedystoma dayi	146	0.7810	Invertebrates and detritus/sediment

Group	Species	n [a]	Coefficient	Main Food Types or Feeding Strategy/Habitat
4 (continued)				
	Arius leptaspis	589	0.7883	Fish (+ macrophyte ingested incidentally)
	Craterocephalus randi	126	0.8491	Invertebrates
	Neosilurus species B	2	0.8566	Detritus/sediment and aquatic invertebrates
	Amniataba percoides	98	0.8665	Aquatic invertebrates and benthic material
	Cynoglossus heterolepis	6	0.8718	Detritus/sediment and aquatic invertebrates
	Liza alata	9	0.8766	Detritus/sediment and aquatic plants
	Hephaestus roemeri	41	0.8780	Generalist
	Crenimugil labiosus	5	0.8784	Detritus/sediment and aquatic invertebrates
	Oxyurichthys papuensis	46	0.9145	Detritus/sediment and aquatic plants
	Arius berneyi	1271	0.9233	Macrophyte material - generalist
	Neosilurus ater	319	0.9537	Benthic feeder

[a] excludes fish examined with empty guts/stomachs

[b] Allen (1991) notes that the presence of *O. lineolatus* in PNG was not confirmed at the time of his book going to press, so the specimens may have been incorrectly identified by OTML's Environment section.

[c] lots of incidental plant matter ingested

[d] recent studies have determined that these species are planktivores, however, earlier studies classified the dietary contents as detritus.

DISCUSSION

Historically, there have been numerous introductions (mostly intentional) of non-native species of freshwater fish to river systems in PNG (West and Glucksman 1976). The first known introduction was the mosquito fish, *Gambusia affinis*, introduced in 1930 by the Public Health Authority for mosquito control (West and Glucksman 1976). Other major introductions include brown and rainbow trout, *Salmo trutta* and *Oncorhynchus mykiss* (in 1949 and 1952 respectively), Mozambique Tilapia *Oreochromis mossambica* in 1954, and Snake-skinned Gourami *Trichogaster pectoralis*, Giant Gourami *Osphronemus goramy* and varieties of Carp (Common, Golden and Cantonese) *Cyprinus carpio* at various times subsequently. By 1974, there were at least 20 species of non-native freshwater fish introduced to Papua New Guinea (West and Glucksman 1976). Intentional introductions have been for mosquito control, sport fisheries, to improve protein deficient diets of inland people, as forage for predatory fish and to establish aquaculture. For example, Coates (1993) reported that Mozambique Tilapia (*O. mossambica*) and Carp (*C. carpio)* were accidentally introduced to the Sepik River, on the north coast of PNG resulting in increased fishery yields. Coates (1993) noted that all native species present prior to the introduction were still in the system 30 years later and suggested that impacts were negligible because the introduced species filled niches not occupied by native species in a system that had a depauperate fish fauna. Introductions continue to date; Coates (1997) indicated that *Tilapia rendalli, Puntius gonionotus, Prochilodus margravi, Collossoma bidens, Tor putitora, Acrossocheilus hexagonolepis, Schizothorax richardsonii* and *Osphronemus gouramy* had been introduced to the Ramu and Sepik Rivers.

Introductions to the Fly River system mostly have been avoided because of the remoteness of the area. However, some upland tributaries of the Strickland River have been actively stocked with Trout. Mozambique Tilapia were unsuccessfully stocked into Lake Murray, on the Strickland River (Figure 1a) in 1960, and Carp were established at Balimo, on the neighbouring Aramia River in 1972 (West and Glucksman 1976). In the mid 1990s, Common Carp were introduced to several village-based aquaculture developments in the upper Fly River (Storey, unpublished). To date, there have been no known escapes to the wild.

The spread of *A. testudineus* throughout the Fly River system, and across the south-west of PNG represents a very rapid invasion by an exotic fish species. The ecological consequences of this introduction have not yet been fully established. Over a twelve year period the species has spread approx. 175 km across the Trans-Fly region and this dispersion continues; in 1994 *A. testudineus* were sampled from the Aramia River to the east of the Fly River and in 1995 unsubstantiated reports of the species were received from further east, on the Kikori River (Ok Tedi Mining Limited, unpub-lished data). The majority of the Trans-Fly area is seasonally inundated floodplain. This would facilitate the spread of *A. testudineus* when waterbodies are interconnected during the wet season providing ease of movement across the floodplain. In addition, because *A. testudineus* can survive for periods out of water, local villagers in coastal regions have reported that they carry the fish in their bilums (string bags) when they go gardening in the forests, to ensure fresh food. This can only assist in the dispersal of what is already a very mobile species.

Within the Fly River system, *A. testudineus* has become established in nearly all habitats. It proliferates in all floodplain habitats and in freshwater and tidal swamps backing onto the estuary. Specimens are regularly taken from the main channel of the Fly River and from the littoral zone in the estuary. These latter areas may not be the preferred habitats, as these fish may be moving from the floodplain and coastal swamps into the main channel/estuary as water levels fall. There is regular interchange of water between the floodplain and the main channel of the Fly River via tie-channels. As water levels in the river fall, water flows off the floodplain into the main channel, and fish would follow this flow as habitats start to dry. One of the authors (REWS) has observed *A. testudineus* crawling between his legs in order to traverse an exposed levee bank from floodplain pools into a tie channel during falling water levels. This vindicates the species common name of 'Climbing Perch' and its reported ability to 'walk' across land (Davenport and Abdul Matin 1980). In the estuary, fish move in and out of coastal swamps and mangrove areas with the 4-5 m daily tidal cycle and local villagers utilise this cycle to catch *A. testudineus* in hoop nets set across tidal creeks on a falling tide; the species has been rapidly adopted into the daily diet of the villagers.

So far, *A. testudineus* have not been recorded from the main channel of the upper Fly River or its major upland tributaries. This may indicate that *A. testudineus* is not a strong swimmer, and its dispersal is restricted by the faster flows. Interestingly, *A. testudineus* has not been sampled from the main body of Lake Murray, although it does occur in adjacent floodplain habitats (Mathew Kawai, Porgera Gold Mine unpub. dat.). This may represent an avoidance of open, clear water habitats by this species.

Given the rapid spread of *A. testudineus* across the Fly River floodplain, it is likely the species will continue to spread across the Gulf of Papua to occupy all suitable habitats within its reach. The drier climate to the east and the increasing elevation and faster flowing waters to the north may be the only barriers to its movement.

Diet is unlikely to restrict the spread of *A. testudineus* as it appears to be an omnivore, ingesting detritus, aquatic and terrestrial insects, plants, molluscs and oligochaetes, all of which are plentiful in floodplain habitats. There were occasional records of fish scales and bones, but no whole fish suggesting these items were ingested as carrion, and were not indicative of piscivory. Dietary intake by *A. testudineus* in the Fly River system was similar to other areas. Nargis and Hossain (1987) described the species as an omnivore, with percentage occurrence of food items in stomachs of 204 specimens consisting of Crustacea (19%), Insecta (4%), Mollusca (6%), fishes (9%), plant debris (47%) and semi-digested material (16%). Dietary content was relatively constant between different areas and over time. Singh and Samuel (1981) described *A. testudineus* as a carnivorous fish and reported that larvae of *A. testudineus* fed voraciously on micro-Crustacea and insects, whilst adults fed on insect groups such as Anisoptera, Corixidae, and Diptera. *A. testudineus* was described as a predator and carnivore by Pandey et al. (1992), who analysed gut contents in relation to gut pH. Food items recorded were Microspora, Protozoa, Rotifera, Cladocera, Ostracoda, fish scales, bones and spines, Decapoda carapace, mud, sand and plant parts.

At this stage, interactions between *A. testudineus* and native species can only be inferred. Estimates of dietary overlap give some indications, although the broad dietary categories give little precision. Of the species with no significant dietary overlap, many are piscivorous or specialist feeders (eg fruit eaters) compared with *A. testudineus* which is a more generalist feeder. Saratoga, *Scleropages jardini* has a greater dietary overlap than would be expected for a piscivore/ *Macrobrachium* prawn feeder. This may be because *S. jardini* also targets terrestrial insects, and presumably accidentally ingests terrestrial plant matter when striking at food items on the water surface.

Of the species which exhibit a significant dietary overlap with *A. testudineus*, there are some anomalies. Earlier studies of *Nematalosa* spp classified the gut contents as mud/detritus (Hortle 1986), whereas a more recent study examined the contents under higher magnification, which allowed microscopic planktonic organisms to be recognised and so reclassified the species as planktivorous (Roderick unpub. dat.). A more recent study using stable isotopes of carbon and nitrogen also indicated *Nematalosa* derives the majority of its energy (carbon) from algal sources (Storey, unpublished data). Thus, *Nematalosa* spp should have a much lower (probably insignificant) dietary overlap coefficient. *Arius leptaspis* is a large predatory fork-tailed catfish, however, due to its habit of foraging in the benthos, it ingests considerable quantities of plant material (much of it terrestrial in origin). This has resulted in a significant dietary overlap coefficient.

For many of the other species with significant dietary overlap coefficients, there is likely to be little dietary competition between them and *A. testudineus*, due to likely differences in habitat preferences, foraging strategies, and dietary preferences not discernible within the broad feeding categories utilised. Some species occupy habitats from which *A. testudineus* have not yet been recorded, and possibly may never colonise. This is likely to be the case in the faster-flowing upland streams and rivers where species such as *Melanotaenia oktediensis* and *Glossogobius concavifrons* occur. It is also likely that other species such as the mullets, *Liza alata* and *Crenimugil labiosus*, and the catfishes *Arius carinatus*, *A. latirostris*, *A. berneyi, Nedystoma dayi*, *Neosilurus ater*, *Porochilus obbesi* and *P. meraukensis*, which appear to be feeding on the same food types as *A. testudineus* may in fact be feeding in different microhabitats, on different prey items within the broad categories utilised in this study or on different size classes of a particular food category.

Of the species with significant dietary overlap, there are a few which may show direct dietary competition. This is based on the gross similarities of their diets, combined with the fact that *A. testudineus* occurs in the same habitats. The species concerned are the Red-Striped Rainbowfish (*Melanotaenia splendida rubrostriata*), the Lake Grunter (*Variichthys lacustris*), the Striped Grunter (*Amniataba percoides*), Obbes' Tandan (*Porochilus obbesi*) and the Sailfin Glass Perchlet (*Ambassis agrammus*). The extent of dietary competition is difficult to determine as the resources for which they compete are extremely abundant (e.g. aquatic and terrestrial insects).

Two other possible sources of interaction between *A. testudineus* and native fish species relate to feeding habit and predation upon *A. testudineus*. The dominant dietary category in freshwater and estuarine populations of *A. testudineus* was detritus. This indicates a bottom feeding habit, whereby fish forage in the benthos for food items. This will likely stir-up the bottom, causing localised increases in suspended sediment concentrations. In relation to interactions between *A. testudineus* and native species in PNG, Kila and Polon (1994) suggested that increased suspended sediment levels may restrict other fish species through reduced oxygen uptake, abrasion of gills and/or reduced visibility. However, the Fly River (and other rivers in the region) is a naturally turbid river system and as such, the fish fauna is sediment tolerant, dominated by catfish that also are benthic feeders. Therefore, this interaction is unlikely to be significant.

An unexpected interaction, which may be significant, is the inadvertent death of piscivores preying upon *A. testudineus*. Dead specimens of *A. leptaspis* are frequently found floating on the water surface with individuals of *A. testudineus* caught in the throat (our personal observa-tions). It appears that when ingested tail-first, *A. testudineus* extend the dorsal and operculum spines thereby locking in the throat of the predator. This is not always the case, as whole specimens of *A. testudineus* have been recorded from the guts of various piscivores (e.g. Barramundi (*Lates calcarifer*), Salmon Spotted catfish (*Arius leptaspis*), and Lutjanus species (*Lutjanus argentimaculatus* and *L. goldei*). In addition, villagers from the floodplain area have noted a dramatic decline in the numbers of Arafura file snakes, *Acrochordus arafurae*, since the arrival of *A. testudineus*. Whilst not specifically recorded, the by-catch of file snakes in the Ok Tedi Mining Limited fish sampling program appears to have declined since 1988. File snakes would be susceptible to suffocation by fish lodged in the throat, blocking the glottis, or through death by infection following rupturing of the oesophagus or stomach by spines of *A. testudineus*.

The general absence of fish from the diet of *A. testudineus* suggests that the species is not a direct threat to fish stocks through predation on larval and/or juvenile fish. This was of particular concern for the commercially-important Barramundi which use coastal swamps as nursery areas. However, there may be indirect effects through competition for shared food resources or through physical disturbance of the habitat, as discussed above.

Size-frequency distributions showed a disparity between freshwater and estuarine populations of *A. testudineus*, the former reaching a larger size. Different sampling methodologies and equipment were utilised in the two areas. This may explain the under-representation of juveniles in freshwater reaches, however, this is not thought to have been the cause for the lower maximum size of specimens from the estuary. Discussions with villagers living in the estuary, who collect and consume *A. testudineus* on a daily basis, suggest that larger individuals, comparable to those caught in freshwater reaches, were never encountered. In support of this, Kila and Polon (1994) caught 271 fish from estuarine and back-water swamps along the coast to the west of the Fly River, and recorded a maximum length of 115.7 mm

Differences in maxima between freshwater and estuarine populations may reflect that the latter are under stress. Salinities in the Fly estuary range from approximately 0.3 to 2.5% between the inner and outer estuary respectively, with *A. testudineus* occurring across this range. Khan et al. (1976) tested salinity tolerance of juveniles of *A. testudineus* (average of 14 mm length and 200 mg weight). At 1.15% there was 100% survival over 120 h, whilst at 1.25% all fish had died after 29 h. Mortality rates increased with increasing salinities above 1.25%, with 100% mortality in 25 min at 3.0%. No data on survival of adult *A. testudineus* at different salinities could be found in the literature.

The ability of *A. testudineus* to stay alive out of water poses a possible threat to the north of Australia. It is feasible that *A. testudineus* could unintentionally be introduced to Cape York, the north-east point of Australia, through the frequent movement of small craft across the Torres Strait from PNG to Australia; *A. testudineus* may survive in the moist conditions in the bottom of a boat for several days and the distance across the Torres Strait may be covered in a few hours. Once present, *A. testudineus* would quickly become established in the abundant suitable habitat found in the wet tropics of northern and north-eastern Australia.

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REFERENCES

Allen, G.R. 1991. Field Guide to the Freshwater Fishes of New Guinea. Publication No 9 of the Christensen Research Institute. Calendar Print Pte Ltd, Singapore. 268 pages..

Chanchal, A.K., Pandey, B.N. and Singh, S.B. 1978. Studies on some aspects of the biology of *Anabas testudineus* (Teleostei: Anabantidae). Matsya 4: 15-19.

Coates, D. 1993. Fish ecology and management of the Sepik-Ramu, New Guinea, a large contemporary tropical river basin. Environmental Biology of Fishes 38:345-368.

Coates, D. 1997. FISHAID Project. Fisheries Improvement by Stocking at High Altitudes for Inland Development. Papua New Guinea. Project Findings and Recommendations. Field document 5, Report No. FOA-FI-PNG/93/007, 41 pages.

Davenport, J. and Abdul Matin, A.K.M. 1990. Terrestrial locomotion in the climbing perch, *Anabas testudineus* (Bloch) (Anabantidea, Pisces). Journal of Fish Biology 37: 175-184.

Hortle K.G. 1986. A Review of Biological Sampling of the Ok Tedi and Fly River Systems, April 1983 to June 1986. Report ENV 86-9. Ok Tedi Mining Limited, Tabubil, Western Province, Papua New Guinea. 202 pages.

Kare, B.D. 1991. Diet of Selected Fish Species in the Fly River System, Papua New Guinea. Post-graduate Diploma thesis, James Cook University, Queensland, 41 pages.

Khan, H.A., Ghosh, B.B. and Mukhopadhyay, S.K. 1976. Observations on the salinity tolerance of *Anabas testudineus* (Bloch). Journal of Inland Fisheries Society of India 8: 111-112.

Kila, I. and Polon, P. 1994. The distribution, density and diet of (Climbing perch) *Anabas testudineus* in the coastal rivers, creek and swamp pools in Western Province. Unpublished report from the Papua New Guinea Department of Fisheries and Marine Resources to the 6th Meeting of the Torres Strait Environmental Management Committee, Mt Hagen, Papua New Guinea. 4 pages.

Maunsell and Partners 1982. Ok Tedi Environmental Study: Supporting Studies, Volume 6: Ok Tedi-Fly River Aquatic Survey - Heavy Metal Review. Unpublished report to Ok Tedi Mining Limited, Melbourne 344 pages.

Mishra, A.P. and Singh, B.R. 1979. Oxygen uptake through water during early life of *Anabas testudineus* (Bloch) Hydrobiologia 66: 129-133.

Nargis, A. and Hossain, M.A. 1987. Food and feeding habit of koi fish (*Anabas testudineus* Bloch, Anabantidae: Perci-formes). Bangladesh Journal of Agriculture 12(2): 121-127.

Pandey, A. Srivastava, P.K., Adhikari, S. and Singh, D.K. 1992. pH profile of gut as an index of food and feeding habits of fishes. Journal of Freshwater Biology 4(2): 75-79.

Ramaseshaiah, M. 1985. The fecundity of Anabantid fishes *Anabas testudineus* (Bloch) and *A. oligolepis* Bleeker (Osteichthyes: Anabantidae) from Lake Kolleru. Matsya 11: 78-81.

Roberts, T.R. 1978. An ichthyological survey of the Fly River in Papua New Guinea with descriptions of new species. Smithsonian Contributions to Zoology, No. 281: 1-72.

Singh, B.R. and Mishra, A.P. 1980. Development of the air breathing organ in *Anabas testudineus* (Bloch). Zoologischer Anzeiger, Jena 205: 359-370.

Singh, K.P. and Samuel, P. 1981. Food, feeding habits and gut contents of *Anabas testudineus* (Bloch). Matsya 7: 96-97.

Smith, R.E.W. 1988. Six-monthly Biology Review, October 1987–March, 1988. Report ENV 88-05, Ok Tedi Mining Limited, Tabubil, Papua New Guinea. 74 pages.

Smith, R.E.W. 1991. Biological investigations into the impact of the Ok Tedi Copper Mine. pages 261-282, In: Lawrence, D. and Cansfield-Smith, T. (Editors) Sustainable development for Traditional Inhabitants of the Torres Strait Region. Proceedings of the Torres Strait Baseline Study Conference. Workshop Series No

16, Great Barrier Reef Marine Park Authority, Townsville.
Smith, R.E.W. and Bakowa, K.A. 1994. Utilization of floodplain water bodies by the fishes of the Fly River, Papua New Guinea. Mitteilungen internationale Vereinigung für theoretische und angewandte Limnologie 24: 187-196.
Swales, S., Storey, A.W., Roderick, I.D., Figa, B.S., Bakowa, K.A. and Tenakanai, C.T,. 1998. Biological monitoring of the impacts of the Ok Tedi copper mine on fish populations in the Fly River system, Papua New Guinea. Science of the Total Environment 214: 99-111
Swales, S., Storey, A.W., Roderick, I.D. and Figa, B.S. 1999. Fishes of floodplain habitats of the Fly River system, Papua New Guinea, and changes associated with El Nino droughts and algal blooms. Environmental Biology of Fishes. 54(4):389-404.
Swales, S. Storey, A.W. and Bakowa, K.A. 2000. Temporal and spatial variations in fish catches in the Fly River system in Papua New Guinea and the possible effects of the Ok Tedi copper mine. Environmental Biology of Fishes 57: 75-95
Welcomme, R.L. 1985. River Fisheries. FAO Fisheries Technical Paper No. 262, 330 pages.
West, G.J. and Glucksman J. 1976. Introduction and distribution of exotic fish in Papua New Guinea. Papua New Guinea Agricultural Journal 27: 19-48.
Zaret, T.M. and Rand, A.S. 1971. Competition in tropical stream fishes: Support for the competitive exclusion principle. Ecology 52: 336-342.